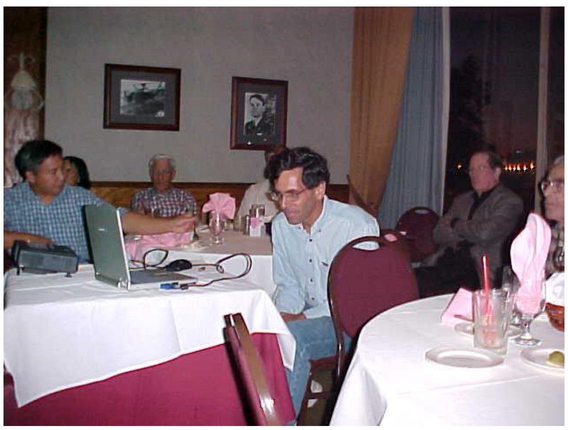
ACHIEVEMENT OF 48 HOUR CONTINUOUS FLIGHT WITH A SOLAR POWERED UAV

Reported by Dr. Clem Hiel, Chairman of the Los Angeles SAMPE Chapter.
Composite Support & Solutions Inc, 464 11th Street, San Pedro, CA 90731
Tel 310 650 6938, e-mail: clemhiel@aol.com

On September 20th, Alan Cocconi of AC Propulsion in San Dimas, CA kicked off the 2005-2006 season of the Los Angeles SAMPE chapter with an outstanding presentation. The photo's below picture Alan. On the left he is operating his laptop during the SAMPE presentation and on the right he his holding his record breaking UAV named SoLong at El Mirage dry lake.



Mr. Cocconi started by stating that a solar powered UAV seems ideal when aiming for high altitude platforms. They fly above the weather, reliably have sun, and stay out of air traffic control lanes. He commented that this is a nice thing if you can do it!

The applications for high altitude platforms are among others:

- Use as an atmospheric satellite: For broadband communication in urban areas one could park the UAV 10 to 15 miles above a city. The advantage is that it is closer to earth than a satellite which has the advantage that it can be brought down to earth at will for equipment updates. Additionally, the antenna's can be much smaller than for a satellite and of course the cost of the UAV is only a fraction of the cost of a satellite.
- Environmental sensing: I.e. to monitor smog movements coming from the industrial zones in the far-East which are now monitored with high altitude balloons
- Environmental sampling: Using a clean UAV one can do continuous data taking and one doesn't measure the mixed in exhaust from the airplane engine.

In 1999 a serious attempt was made when Aerovironment fielded the "Helios" which is pictured in the photo below. It had a 200 ft wingspan and set an altitude record of 96,863 feet.

NASA Dryden flight Research Center Photo Collection
http://www.dfrc.nasa.gov/gallery/photo/index.html
NASA Photo: ED03-0152-2 Date: June 7, 2003 Photo By: Carla Thomas

NASA's Helios Prototype electrically powered flying wing began a checkout flight June 7 from the Navy's Pacific Missile Range Facility on the Hawaiian island of Kauai.

This was a wonderful achievement but the airplane was also supposed to stay-up overnight. To do that it was relying on fuel cell technology that really did not exist yet. It relied on cells using hydrogen and oxygen in the regeneration mode. The problem is that if any of that comes out as water vapor one never gets it back. As a result the re-circulating fuel is lost as ice plated on the inside of the tank. The airplane crashed in June 2003 on its first flight with fuel cells on board due to autopilot control difficulties resulting in divergent oscillation and subsequent structural failure.

In the last couple of years laptop batteries have improved to the extent that perpetual flight came within reach. Indeed, the rate of performance increase of those batteries has been 10% per year for the last 10 years. There is no reason why this trend shouldn't continue for many years to come. The developers of laptop batteries do believe in it and plow 20% of their sales back into R&D which is enormous.

Others had also come to the realization that perpetual flight had come within reach, and efforts started at a Swiss University with European Space Agency funding. A second Swiss project is an attempt to fly a solar powered manned airplane with a 250 feet wingspan around the world. (this is a development by the Picard Group…the same Picard who flew a record breaking journey around the world in a balloon). The UK defense agency is currently also funding a project. These efforts are all in the planning stages and none of them have achieved flight yet.

Four years ago Cocconi came to the realization that there was a window of opportunity to make a mark and be the first to achieve perpetual flight. Because of his limited resources and manpower, he used the available technology of ion-lithium laptop batteries and

capitalized on the improvements which were made year after year by the battery manufacturers.

It turned out that an important milestone towards the success of the UAV project was laid many years earlier when working on a seemingly unrelated electronics project. It concerned the design of a solar powered conditioning unit. With this unit one could convert the power generated by solar roof panels into AC and dump it into the grid. By injecting a small voltage ripple they found a way to track the “power operating point” of the solar panel. At the time it was just an interesting thing to do for the stationary roof panel and the advantage was not tremendous for residential applications. They found in later years that it was essential when solar panels are subject to rapidly changing conditions such as in electric cars and electric airplanes.

The opportunity to prove this came in 1987 when the GM-Sunracer used Coconi’s power tracking technology leading to a huge advantage. In the Pentax World Solar Challenge 1997 race through Australia a General Motors Sunracer vehicle won with average speed of 71 km/h. It won the race by 2.5 days. What happened is that many of the competitors had done their testing in the lab, but when their vehicles were in the field and they passed the shadow of eucalyptus trees every 100 yards, the solar panels got completely confused.

In 1991 AC propulsion was formed and got involved in the EV-1 and other electric cars. They developed and electric drive system of 165 KW which could be driven 100 miles for every hour of charging.
In that timeframe they also build the “tzero” sports car, which is shown below, and is capable of going from 0 to 60 mph in 3.6 seconds.

To achieve this they used 68 bricks of 100 batteries each or a total of 6800 batteries ($ 30,000 worth of batteries). Each brick was wired with 4 volt batteries in series giving a 400 volts output. The bricks are housed between the wheels and the sides, which explains why the doors are so small and why one has to go through the roof to get into the car. The battery pack is good for 4 years or 500 to 1000 cycles. With new developments in the

longevity of batteries a 10 years lifetime will become a reality. An interesting statistic is that if 50,000 of these cars were build per year with these batteries, this market would only amount to half the size of the laptop market.

One key component which was used of the shelf is called an “ironless” motor, manufactured by Kontronik in Germany. The word “ironless” does not mean that there is no iron in it, but well that there are no iron losses. The way they achieve that is that the stator rotates with the rotor, so that the true stator left is the copper winding. Therefore the magnetic field in the iron is invariant and the only losses are in the resistance of the copper and some slight eddy current losses. This motor is ideal for high rpm and light load operation. However, in order to work for the UAV project, an 8 to 1 power range from takeoff to cruise was required since the maximum rate of climb was 10 ft/sec and sometimes there are downdrafts making the sky sink at 10 ft/sec. In order to make one motor satisfy the 8:1 power requirement Cocconi described an enabling technology in the form of a patented split phase transformer that uses nine phases and could now drive this wonderful motor through its entire power range.

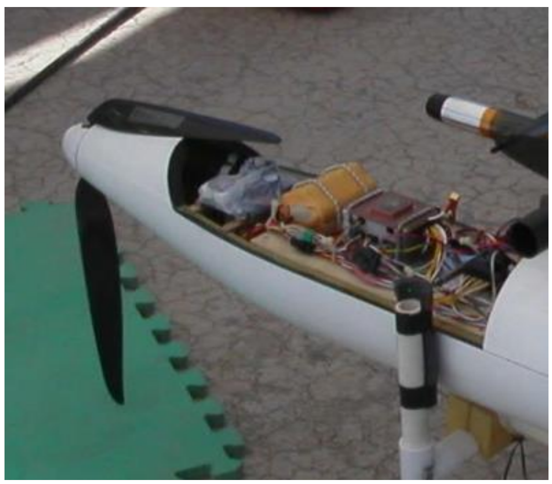
Mr. Cocconi then led the audience through a number of UAV projects which he did to move up the learning curve and each time to implement one more component (avionics, navigation, control, algorithms, etc…) of his vision towards perpetual flight. Along the way he showed their endeavors into composite construction using carbon and Kevlar for the spars and monocoque structure and moldmaking. The integration of the solar cells into the wings is not a straightforward process. One can think of the 10 mill thick solar cell as a microscope cover slide piece of glass. It is a very springy rigid piece of material that has to be integrated into the wing. A whole molding process had to be developed to be able to do this. They needed metal molds which were stable and had no compound curvature so that they would not crack the solar cells.

Shown below is one section of the six-piece wing.

The solar cells contribute to the stiffness of the wing and to compensate for this, the bottom skin was made thicker than the top skin. All curing needed to occur at 45 C

because it was found that at higher cure temperatures the CTE difference between the composite and the solar cell created too much stress and posed serious difficulties.

First the solar cells were completely flat and cured onto glassfiber with Rohacell foam behind it. This was allowed to B-stage and subsequently vacuum bagged into the mold.
The A300 cells from Sunpower were used since they are the current state of the art. They further have the advantage that they are 5 in^2 cells and that all contacts are on de back side which allows for a laminar flow wing.
They also used a variable pitch propeller which showed a 10% efficiency gain as compared to a fixed pitch and was of enormous help. In order to get data on the airplane performance they used a load cell on the motor and developed good motor efficiency data while flying. This data was later mapped into a lookup table which proved very useful during the 48 hour flight because it gave them the best possible propulsion efficiency at all times.
The batteries consisted of 8 modules of 15 laptop cells weighing 43 grams a piece each.
When the propeller is not spinning it flops back in a low drag configuration as shown below.



This allowed landings on a 2” foam skid and there was thus no need to carry the weight of a landing gear. The airplane takes off from a PVC dolly. The tracking is done from a utility trailer where the data-screen and the flight screen display the information, including the video-feed data that was needed by the eight pilots on the ground to make it through the 48 hour endeavour.

A first 24 hour trial flight on April 19, 2005 they learned that although it may seem quite during the night the air is in complex movement and attention is required at all times.
The 48 hour flight occurred on June 1. They took off at 4:00 P.M. and caught thermals and made it through the first night with 3 hours of reserve power in the battery. The next day suddenly all lift disappeared and they encountered a 3-5 meter/sec sink rate everywhere within a 4 mile radius. This happened two nights in a row and was dubbed by the team as “afternoon terror.” To overcome this they had to run the motor at full power for 10 to 15 minutes. They came out of the second night with 1 hour of battery power reserve. Some tricks they tried were to run tight banks in order to catch the sun early in

the morning. With the sun higher in the sky at 10:00 A.M they knew they were going to make it. At the time of landing at 4:00 P.M. the battery was pretty full.

This multi-day flight happened in ideal conditions on a clear summer day with moderate wind. The whole flight occurred below 2500 meters. NBC-TV came out on June 3 to broadcast the record breaking 48 hour flight to a National audience.

The SoLong can sustain multi-day flight only in favorable conditions. A practical UAV needs to operate above the weather and over 80,000 feet. The technical developments required to get there are:

- Higher specific energy batteries of 400 watt hour/kg (in the SoLong the used 220 Watt hour/kg). Batteries for cell phones and laptops make use of new chemistries such as lithium-sulfur.
- 30% efficiency solar cells with a weight off less than 100 grams/m^2 (in the SoLong they used cells which are 20% at 23 grams/m^2). Solar cells with 30% efficiency are currently available at a cost of 100K/m^2. Lighter and cheaper ones are due to emerge in the next three years.
- Battery to mass fraction of 80% (in the SoLong it was 44%). Burt Rutan has already achieved 90% flying the Voyager.
- Aerodynamics refinements for a sink rate of 0.3 m/sec (down from .55 m/sec in the SoLong)
- Autonomous flight management control software and collision avoidance.

The priorities for success are:

- Battery and solar cell development are beyond the scope of any national or international solar aviation program that is currently being pursued. There is no reason why the current trend of 10% improvement per year won't continue into the foreseeable future.
- Concentrate resources on areas that can benefit from application of existing technology.
- Be in a position to optimally use the latest battery and solar cell developments as soon as they become available.